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RESEARCH MEMORANDUM

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MANEUVER PERFORMANCE OF INTERCEPTOR MISSILES

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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SUMMARY

From an analysis of a point defense against ballistic missiles with an intercept near an altitude of 140,000 feet, a lift coefficient from 2 to 3 is shown to be required of the antimissile missile. This lift is readily obtained from missile configurations having small low-aspect-ratio surfaces and even from bodies alone at higher angles of attack. Preliminary wind-tunnel tests at Mach numbers of 4.65 and 6.8 have indicated trailing-edge controls to be poor in trimming a low-aspect-ratio configuration to the required lift, whereas an all-movable forward surface with a short lever arm on a flared-skirt configuration shows adequate trim lift characteristics. These preliminary analyses and wind-tunnel tests indicate that more research should be done on controls, either aerodynamic or reaction type, so that interceptor-missile configurations may be trimmed to the angles of attack required to develop the necessary turning force.

INTRODUCTION

The performance criterion for an interceptor missile to defend against ballistic missiles is turning force sufficient to intercept the target as well as drag characteristics that do not degrade the ability of the rocket motor to obtain high altitude and range in a short length of time.

SYMBOLS

C_L lift coefficient

C_N normal-force coefficient

$C_{N,TRIM}$ trim normal-force coefficient

g	acceleration due to gravity
L/D	lift-drag ratio
$(L/D)_{TRIM}$	trim lift-drag ratio
l	length of missile
M	Mach number
t	time, sec
Δt	incremental time, sec
x	distance from nose to center of gravity
x/l	center-of-gravity location
α	angle of attack, deg
α_{TRIM}	trim angle of attack, deg
δ, δ_c	deflections of control surface, deg

DISCUSSION

In order to aid in determining the aerodynamic lifting force that may be required of an antimissile missile, a purely arbitrary problem of intercepting an intercontinental ballistic missile (ICBM) was set up. A point-defense problem was considered. Figure 1 presents the conditions, trajectories, and requirements for an antimissile missile that is maneuvered by aerodynamic forces and aerodynamic controls. The arbitrary conditions for point defense were to intercept an ICBM warhead at an altitude of 140,000 feet at a minimum range from launch of 40 nautical miles. The missile considered consisted of a so-called aerodynamic steerable stage that places the warhead stage at 140,000 feet in 50 seconds so that the warhead stage may make the final correction to intercept (in the order of 2 nautical miles) in several more seconds. In the figure, altitude is shown plotted against horizontal range. The ICBM path enters at 20° and the antimissile launch point is somewhere beneath this path. If atmosphere is not considered, the zero point on the range is the extension of the ICBM path to theoretical impact. The curved trajectories illustrate the paths of the antimissile for two different turning forces or lift. In detail, the missile is launched at 70° and

boosted to a Mach number of 6 between altitudes of 20,000 and 30,000 feet in nonguided flight. Then the missile coasts and makes an "aerodynamic turn." For example, two turns are shown: one for a lift coefficient of 2 for a duration of 15 seconds and another for $C_L = 3$ for a duration of 5 seconds. A value of C_L of 3 causes the missile to turn too much for this 70° launch angle; however, if the launch angle were 80°, a value of C_L of 3 would be required to obtain a trajectory similar to the one shown fully. At the end of this "aerodynamic turn" the sustainer rocket is fired to accelerate the missile to $M = 10$ so that the desired intercept point may be reached in time. The latter part of the path is a ballistic trajectory to the point of near intercept.

The important point of this trajectory analysis is that lift coefficients, based on body cross-sectional area, in the range of 2 to 3 are required for maneuver performance. This represents normal accelerations in the order of 30g. Also, note that when the missile is at high angles of attack in the denser air the Mach number is not excessive.

Configurations that are capable of producing lift forces of this magnitude have been tested in wind tunnels and are reported in references 1 to 5. Two configurations having different aerodynamic controls and their trim capabilities will be shown for Mach numbers of 4.65 and 6.8 as obtained in the Langley Unitary Plan wind tunnel and in the Langley 11-inch hypersonic tunnel. The two configurations are shown in figure 2. Based on body length, the Reynolds number is 12.5×10^6 for the data at $M = 4.65$ and 3×10^6 for the data at $M = 6.8$. Figure 3(a) summarizes the results at $M = 4.65$ for a low-aspect-ratio long-chord delta cruciform configuration having trailing-edge controls. Plotted as the ordinate is the trim normal-force coefficient based on body cross-sectional area against the center-of-gravity location for two deflections of the controls. These data show that in order to reach required values of normal-force coefficient from 2 to 3, the static stability must be quite low, in fact, near neutrally stable. The boundary mark indicates the position of neutral stability. This is realistic because neutral stability should be no problem inasmuch as the moment characteristics of long-chord configurations are so nearly linear and have no adverse static stability characteristics. Note that trim angles of attack around 15° are required. The static margin to obtain values of C_N from 2 to 3 is in the order of 0.2 body diameters, the value at which various controls are compared in reference 6. Shown again in figure 3(b) is the trimmed lift effectiveness at $M = 6.8$. Note the severe reduction in effectiveness of the trailing-edge controls that are directly behind the wing. Of course, at a Mach number of 6.8 the trailing-edge controls are incapable of producing the required values of C_N from 2 to 3. If these controls were all-movable and interdigitated with respect to the wings, the large reduction in effectiveness would not occur at $M = 6$ as pointed out in reference 6.

The drag penalty which goes with these trim lift conditions is shown in figure 4 as the trim lift-drag ratio plotted against center-of-gravity location for a Mach number of 4.65. These results also emphasize the need for low static margin to obtain better values of $(L/D)_{TRIM}$. The untrimmed L/D capabilities of this configuration are slightly better than 3 as compared with $(L/D)_{TRIM}$ of slightly over 2. Therefore, the trailing-edge controls are incapable of producing the full L/D capabilities of the configuration.

A different configuration is presented in figure 5(a). Shown is $C_{N,TRIM}$ plotted against center-of-gravity location for a flared-skirt-stabilized configuration with an all-movable surface just in front of the center of gravity. Data for two deflections of the control surface are presented. Again for even this configuration the static stability must be quite low at $M = 4.65$ to obtain the required values of $C_{N,TRIM}$ from 2 to 3. Note that the trim angles of attack are near 12°. The control lift effectiveness is quite high, accounting for the trim capabilities. Shown in figure 5(b) is the trimmed lift effectiveness at $M = 6.8$. At this higher Mach number, ample $C_{N,TRIM}$ capabilities are available for this configuration at trim angles of attack near 14°.

The trimmed lift-drag characteristics of the flared-skirt configuration under these conditions are shown in figure 6(a) for $M = 4.65$ and in figure 6(b) for $M = 6.8$. The trimmed lift-drag characteristics are no better than for the long-chord delta configuration, but the untrimmed lift-drag ratio for the flared-skirt configuration is only slightly better than 2. Therefore, the all-movable forward surface develops $(L/D)_{TRIM}$ capabilities that are the maximum available from the configuration.

The preceding data indicate that aerodynamic controls may be a problem for the antimissile missile. That is, the all-movable-surface configurations may have severe heating and interference effects, and the trailing-edge controls are ineffective at high supersonic speeds. However, the aerodynamic lifting capabilities are adequate. Therefore, this suggests some form of nonaerodynamic or reaction control for trimming.

For purposes of comparison, another analysis was made for a hypothetical wingless missile to do the same arbitrary point-defense job as the winged aerodynamic-controlled missile. The basic premise of this analysis was that the turning force would come from the body lift and the component of the thrust vector due to angle of attack only.

Therefore, the booster or sustainer rocket motors must be active during the entire 50 seconds of flight to 140,000 feet. Figure 7 presents the trajectory and requirements for this wingless configuration. Plotted is the altitude against the horizontal range for the trajectory shown. The missile is launched at an angle of 70° and at an altitude of about 20,000 feet the turn begins while the booster is burning. This turn requires a lift coefficient of about 2 (based on body cross-sectional area). Most of the turn is accomplished during boost where the Mach number varies slowly between 4 and 6 in the denser air, the interval between 13 seconds and 30 seconds. Then, the booster drops off near 80,000 feet and the missile, still utilizing body lift and using a two-step-thrust or dual-thrust sustainer motor, completes the turn into the required trajectory in the required time to place the warhead stage at 140,000 feet in 50 seconds. Above the trajectory plot in figure 7 is shown the effective lift-drag ratio experienced during this particular programed turn. The solid line indicates the total effective lift-drag ratio, which is the sum of the aerodynamic lift-drag ratio and the components attributed to the rocket thrust. The dashed line shows the aerodynamic lift-drag ratio of the body alone involved. Also shown is the angle of attack to develop the required lift coefficient and the tilting of the thrust vector. Note that at the beginning of the turn most of the turn is accomplished with body lift whereas, as the altitude increases (that is, as the aerodynamic lift and drag in pounds become smaller), the tilting of the thrust vector is of greater importance.

CONCLUDING REMARKS

From these preliminary wind-tunnel tests of interceptor missile configurations and the analysis of point defense against ballistic missiles, it is concluded that adequate aerodynamic lift is readily available and should be utilized when operating under high-dynamic-pressure conditions and that more work should be done on controls, either aerodynamic or reaction type, so that the configurations may be trimmed to the angles of attack required to develop the necessary turning force.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., March 19, 1958.

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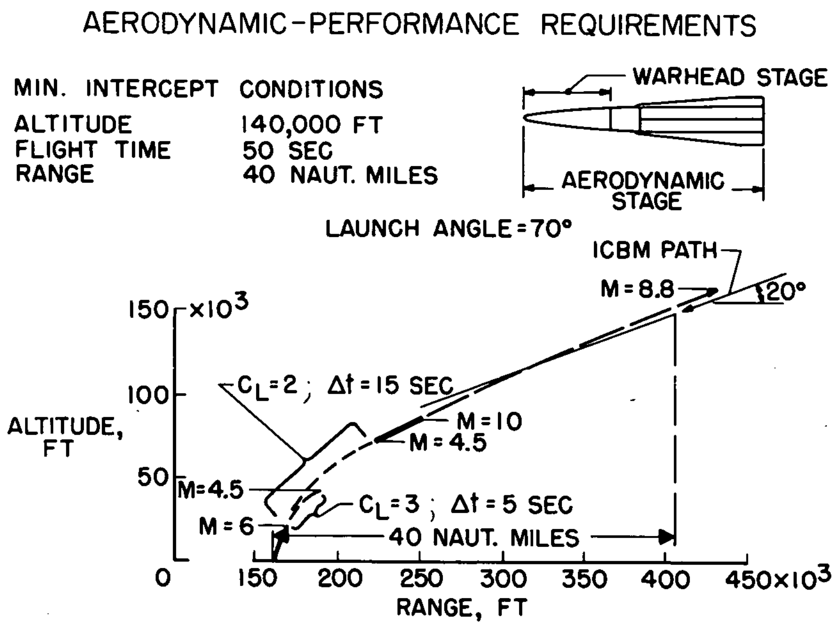

Figure 1

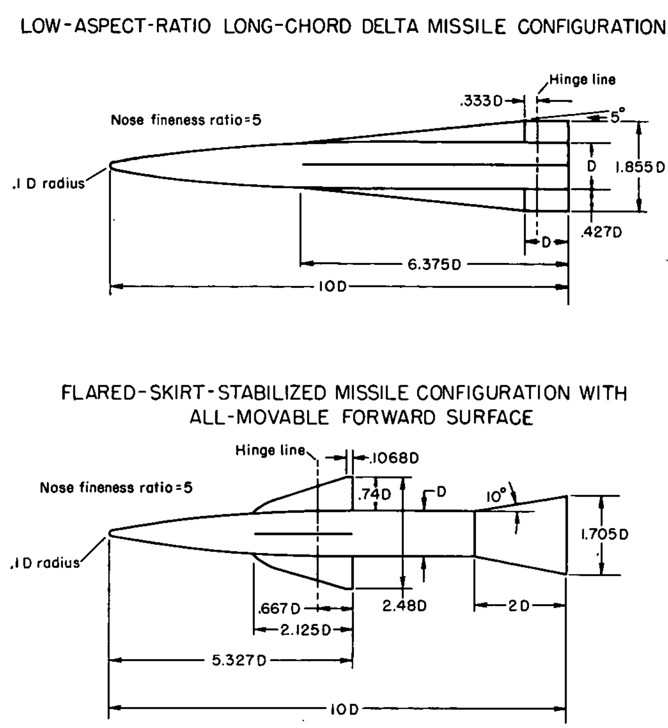

Figure 2

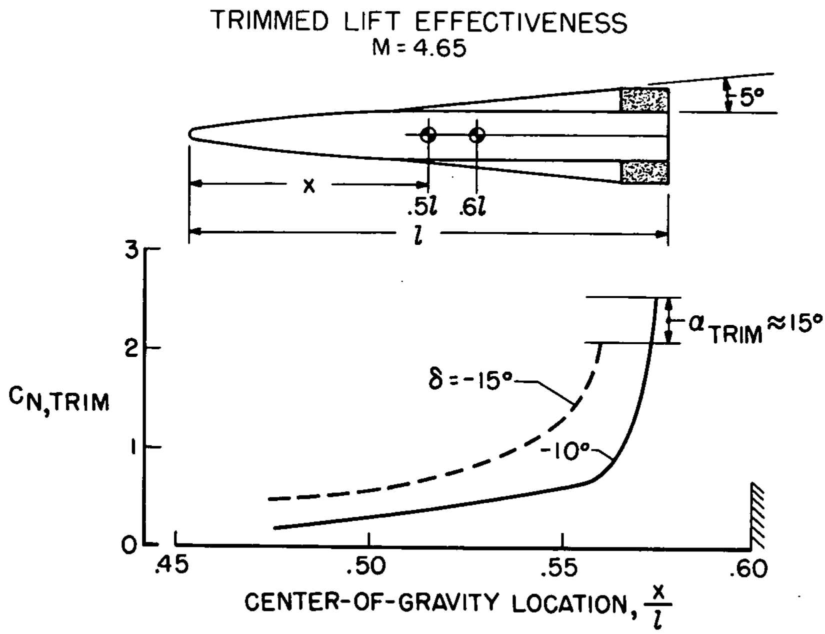

Figure 3(a)

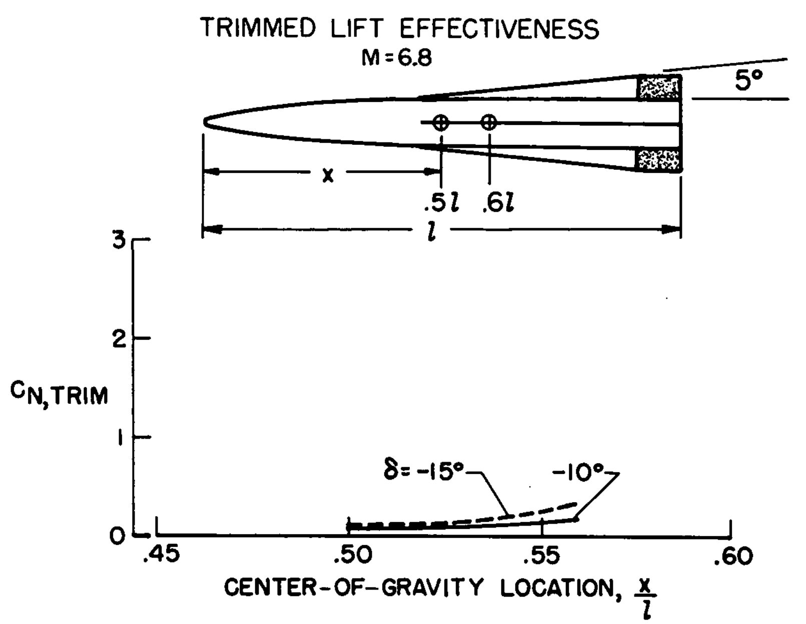

Figure 3(b)

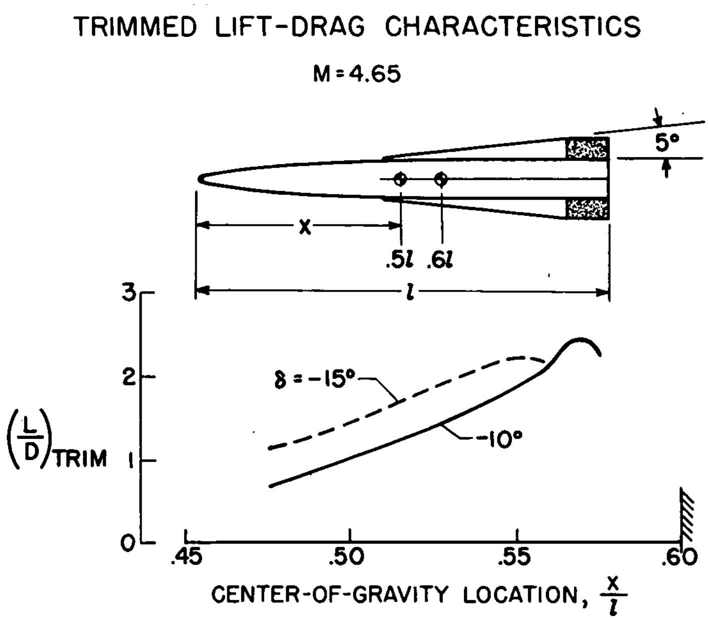
TRIMMED LIFT-DRAG CHARACTERISTICS
M = 4.65
5°
x
.5l .6l
l
3
2
1
0
(L/D)TRIM
δ = -15°
-10°
.45
.50
.55
.60
CENTER-OF-GRAVITY LOCATION, x/l

Figure 4

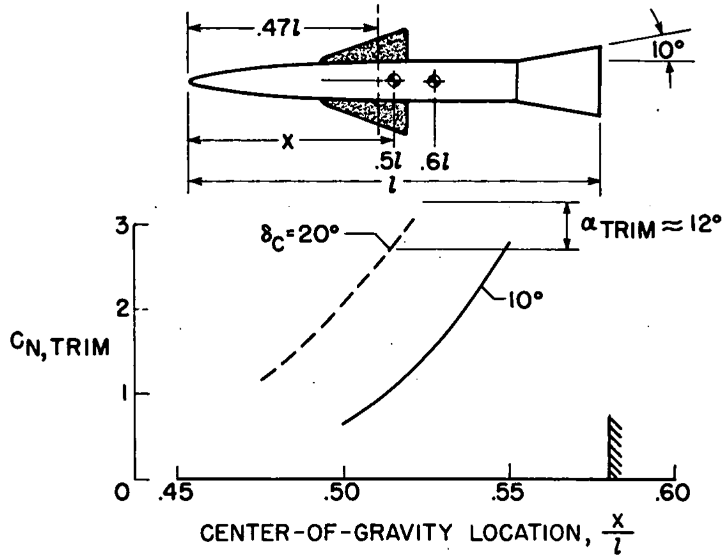

Figure 5(a)

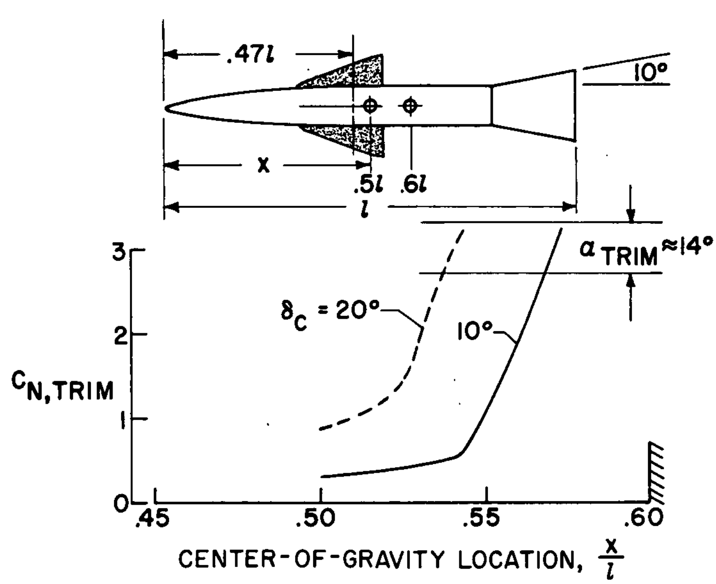

Figure 5(b)

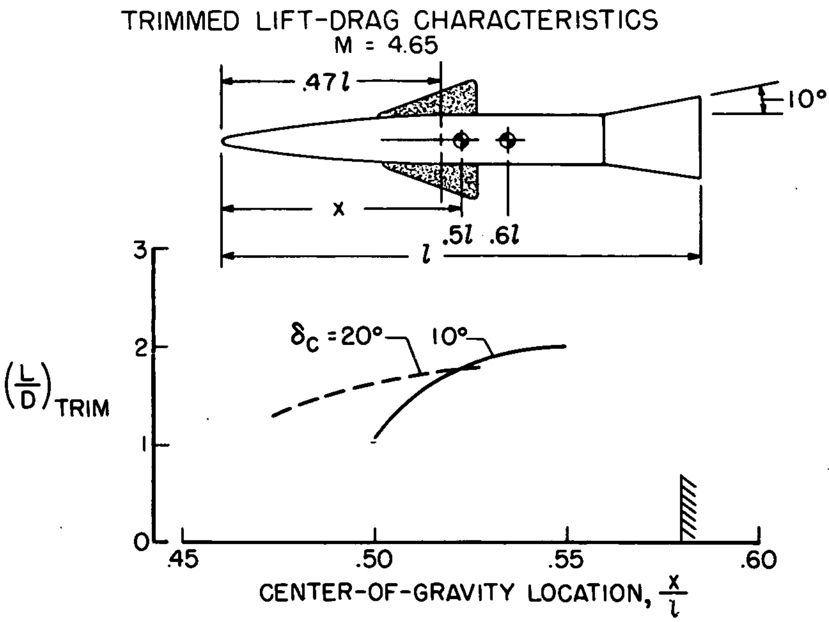

Figure 6(a)

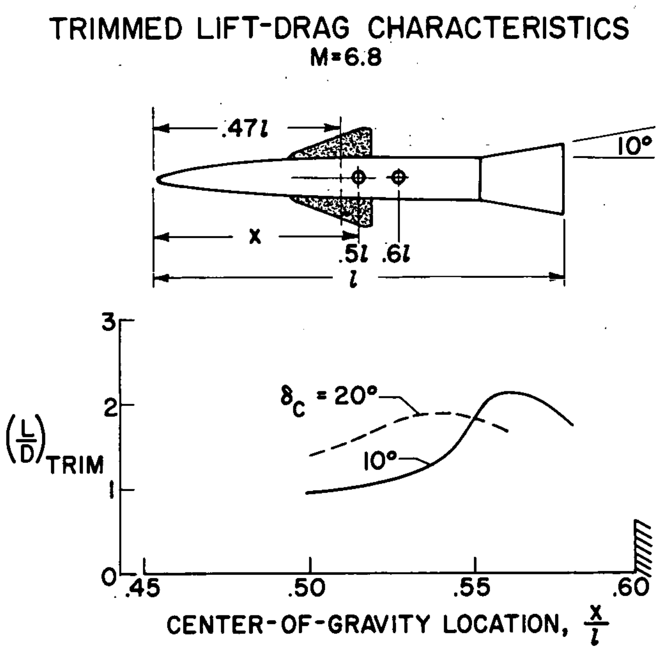

Figure 6(b)

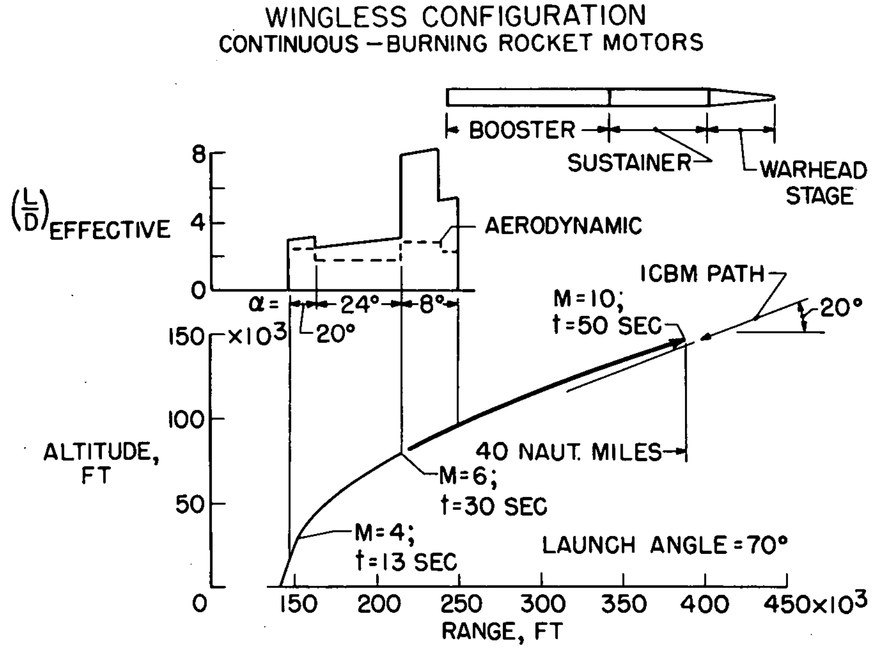

Figure 7

NACA - Langley Field, Va.